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Active learning pedagogy: Structuring the pre-instruction assignment

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Abstract. Education research is changing the way teachers teach and students learn. In contrast with the lecture-based approach to instruction, centered on the teacher as "performer", teaching and learning activities now place equal emphasis on in-class and out-of-class work. Much of the interaction between at-home activity and classroom experience and is mediated by information technology tools. Students are technology savvy, comfortable in the world of on-line delivery of information and social media interactions. To be an effective player in this world, instructional design has to follow the students. Contrary to the opinion that the introduction of technology into the teaching and learning process will diminish the role of the teacher, we believe that the opposite could be the case. Communication technology can enable all students to be exposed to the best and most charismatic lecturers. Electronically enabled social media forums can give rise to much more individualized interactions between students and instructors and students and students than what was ever possible. In this paper, we focus on some pedagogical approaches that allow the students to prepare themselves for interactive classroom engagement. The techniques we describe are labelled Just-in-Time Teaching and Worked-Examples. These involve carefully crafted assignments that students complete before going to class. The results of these assignments, completed just before class-time and available to the instructor, prepare the both for a more productive in-class experience.

1. Introduction

Over the past several decades teaching and learning activities have shifted from passive, instructor-centered to active learner-centered approaches [1] Variously labelled active learning or interactive engagement, the main point of the strategy is "that it involves students in doing things and thinking about the things they are doing. [2]." Today's classrooms include a kaleidoscope of "non-traditional" students: older students, working part-time students, commuting students, and, at the service academies, military cadets. Providing consistent, friendly support can make the difference between a successful experience and a fruitless effort. It can even mean the difference between graduating and dropping out. Education research has made us more aware of learning style differences and of the importance of passing some control of the learning process over to the students. Active learner environments yield better results even though they are harder to manage than lecture-oriented approaches [3].

Cognitive research links student construction of new knowledge to students' pre-existing ideas about the world. In addition, there is a body of research that looks at how students' motivational beliefs and classroom contextual factors affect conceptual change [4].

It turns out that faculty background is not the only, and not even the most important, factor determining a learning outcome. A 2011 experiment at University of British Columbia [5] showed that

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the structure of the instructional strategy has a significant impact on the learning outcomes. From the paper abstract: “We compared the amounts of learning achieved using two different instructional approaches under controlled conditions. We measured the learning of a specific set of topics and objectives when taught by 3 hours of traditional lecture given by an experienced highly rated instructor and 3 hours of instruction given by a trained but inexperienced instructor using instruction based on research in cognitive psychology and physics education. The comparison was made between two large sections (N=267 and N=271) of an undergraduate introductory physics course. We found increased student attendance, higher engagement, and more than twice the learning in the section taught using research-based instruction.” The experimental section lessons were highly structured with pre-instruction assignments and interactive lesson activities that included clicker-questions-based discussion, group work and mini-lectures. While this approach may be non-intuitive to traditionally trained instructors, it is hard to argue with the data that show that the experimental section outperformed the traditionally taught section by 2.5 standard deviations.

In a 2014 article Scott Freeman and colleagues report on a meta-study involving 225 studies and 29000 students in various STEM discipline [6]. Some students attended lecture only classes, others were in various interactive settings. The authors report that interactive classes improved exam performance by half a standard deviation and lecture-only classes increased failure rate by 55%. Apart from obvious benefits to students, the authors point to some interesting broader issues. Based on conservative assumptions, the results of the studies translate into over US$3500000 in saved tuition dollars for the study population, had all students been exposed to active learning. If active learning were implemented widely, the total tuition dollars saved would be orders of magnitude larger. In another interesting side remark the authors point out that if the experiments analyzed here had been conducted as randomized controlled trials of medical interventions, they may have been stopped for benefit—meaning that enrolling patients in the control condition might be discontinued because the treatment being tested was clearly more beneficial.

In a 2009 article cognitive scientist Michelene Chi develops a hierarchy of learner activities that, ranging from active, through constructive to interactive, lead to better and better learning outcomes [7]. Being active can be characterized as doing something while studying. Another set of overt activities that students can perform while studying can be characterized as more constructive because in undertaking them, learners produce some additional outputs; and such outputs often contain new content-relevant ideas that go beyond the information given. Being interactive can refer to several types of overt activities, such as a learner talking with another person (who can be a peer, a teacher, a tutor, a parent) or responding to a system (such as an intelligent tutoring system, an animated agent). In the article Chi argues that extensive research shows that interactive activities lead to the best and most lasting learning outcomes.

Research recommends that learning units start with an examination, by the student, of his/her current knowledge regarding the topic to be studied, and with an examination of motivational beliefs that determine the student’s approach to the topic. This approach is currently favored in any setting, but it is particularly appropriate when the audience is non-traditional students who need to be given some control over what they do to avoid slipping into surface learning which creates a dichotomy between their other (to them meaningful) activities and going to school (not to learn but to get certified for something.) We believe that carefully structured pre-instruction learning modules prepare students for a more productive time with a live teacher. The pre-instruction assignment informs the student and the instructor and sets the stage for a live lesson, which is then on a much higher level and closer to meeting the needs of the audience in the classroom than a traditional generic lecture.

In this paper, I describe two approaches that guide student through activities, which aim to achieve the goals outlined above. The first one, Just-in-Time Teaching [8], has been around for over twenty years. We introduced it in 1996 to take advantage of the internet. In the intervening years it has been adopted in all STEM disciplines and in many humanities disciplines [9]. The second initiative described in this paper, worked-examples, is work in progress that also shows much promise.

You are preparing an introductory biology lesson on cloning. You would love to face a class that has done some preliminary reading, has thought about the subject, and has some questions for you. Don’t we all wish for that? Well, it can happen.

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2. Just-in-Time-Teaching (JiTT)

When Kathy Marrs at is preparing her lesson on genetics she sends her students to the course website and invites them to ponder some warmup questions [10]. After some thought, students post their attempts at answers on the course site from where Kathy retrieves them just before class. She carefully weaves the student thoughts into her lesson.

A sample question: Dolly the sheep is a genetic twin, or clone, of a sheep that was born 6 years earlier than Dolly. Read the material for today. Does Dolly have parents? If so, who were her genetic parents? Is Dolly a "virgin birth"?

Two student answers:

A. That's a hard question. She was cloned from the cell of a 6-year-old sheep. Dolly doesn't have what we would commonly think of as parents, but genetically her parents would be the same parents of the six year old sheep. So, her parents would be the parents of the sheep she was cloned after.
B. Dolly does have genetic parents. Those being the parents of the sheep who was born six years earlier. Dolly would have the same genetic makeup as the sheep before, who has gotten her genetic makeup from her parents.

The Just-in-Time Teaching strategy pursues three major goals:

- To inform instructors about students' thinking. What do they know when they come to class? What have they learned from recently-assigned reading? What connections have they made based on this reading? And, how do students feel about course content?
- To structure the out-of-class time for maximum learning benefit by students.
- To provide information and content so that instructors can maximize the efficacy of the live classroom session.

Although Just-in-Time Teaching makes heavy use of the web, it is not to be confused with either distance learning nor with computer-aided instruction even though it is used in both of those settings. All JiTT instruction occurs in a classroom with human instructors. The web materials, added as a pedagogical resource, act as a communication tool and as an organizer. Since much of the learning occurs outside the classroom, JiTT practitioners view their pedagogical strategy as feedback loops between teaching and learning and between in-class and out-of-class experiences.

The JiTT classroom differs from the traditional lecture in two significant ways: First, having completed the web assignment just before class time, the students enter the classroom ready to participate actively in the activities. Secondly, students have a feeling of ownership because the interactive lesson is based on their own wording and understanding of the relevant issues.

JiTT is used in many disciplines at many levels. JiTT assignments vary significantly from discipline to discipline and from instructor to instructor.

A good JiTT question:

- Yields a rich set of student responses for classroom discussion.
- Requires an answer that cannot just easily be looked up.
- Encourages the student to examine his/her prior knowledge and experience.
- Requires that the student formulate and justify the response, including the underlying concepts, in his/her own words.
- Contains enough ambiguity to require the student to supply some additional information not explicitly given in the question. (This feature enriches the subsequent classroom discussion).

Here are eleven "good" JiTT questions:

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1. Introductory Biology: What is the difference between a theory and a belief? You may want to look these terms up before answering. Be as specific as you can and give an example of each (Marrs).
2. Logic: The people of finiteland only tell the truth on Sunday, Tuesday, and Thursday. Which day of the week is it if a person from finiteland says, "I told the truth yesterday"? (Watt).
3. Introductory Physics: Please explain in your own words what a focal length is. Try not to use any equations or refer to a specific type of mirror or lens (Gavrin).
4. Introductory Earth Science: When reading or hearing news reports about dinosaur discoveries, what questions should you think about and ask yourself to evaluate the accuracy of the reports? (Guertin).
5. Advanced Mechanics: Your everyday experience, common sense, and math classes all suggest to you that the shortest distance between two points in two-dimensional space is a straight line (unless, of course, you want to consider a warped space-time continuum!). Please describe how you would go about proving that this is true, using the methods of variational calculus. Don't actually do this but describe in English the procedure you would follow. Please be specific in your steps. (Patterson).
6. Chemistry: Explain in simple terms how you solved warm-up #1. In particular, what questions did you ask yourself and what conclusions did you draw from the answers? (Blake).
7. Statistics: Estimate the probability that a North American male is precisely six feet tall. (Watt).
8. Introductory Physics: Let's say you have a prescription for contact lenses of -2 diopters. If you accidentally get glasses (as opposed to contacts) made to the same strength, your prescription will be a bit off, and you won't be able to focus at infinity. Estimate how far you will be able to focus. (Gavrin).
9. Earth Science: In your opinion, do we need to save ancient Egyptian monuments? Why? What are the monuments worth - are they worth anything? (Guertin).
10. Economics: Imagine that you are a newspaper reporter assigned to write a story about the upcoming meeting of the Federal Open Market Committee. Make a list of three questions that you will want to ask. For each question, explain carefully why it is important and what answer you expect from the Committee (Maier).
11. Introductory Biology: Allison is driving with her parents, Kate and Bob, when they get in a serious car accident. At the emergency room, her doctor (you) tells Allison that her mother is fine, but her father has lost a lot of blood and will need a blood transfusion. Allison volunteers to donate blood, and you tell her that her blood type is AB. Bob is type O. (a) Can Allison donate blood to Bob? Why or why not? (b) Allison, who is a biology student, begins to wonder if she is adopted. What would you tell her and why? (Marrs).

The questions illustrate some of the broad categories targeted by the pre-instruction assignments:

1. Preparing for a discussion of a complex, possibly controversial topic. Student classroom participation will be enhanced if they come in with informed opinions that they are eager to defend. Examples above: (1)(9) (11).
2. Creating a need to know. Good questions are sufficiently captivating so that even weak students may be interested in the answer. It is up to the instructor to build on this emerging motivation and sustain a lasting interest in the subject. Examples above: (2) (11).
3. Going beyond the bare definition. In many subjects, dry definitions of technical terms and complex concepts leave the students disinterested at best and often perplexed and confused. They then resort to coping strategy that disconnects the subject taught from the real-world experience. The physics community is well aware that erroneous perceptions of how the physical world works persists after successful completion of a physics course. Students function in two worlds, the everyday real world, and the “physics” world. It is very helpful to the student if he/she is challenged to digest the new enough to be able to construct his/her own formulation of the new ideas, crude as such formulation may be, to fuse the two worlds into one. “In your own words…” kinds of questions fall into this category. Examples above: (3)(5)(8).

4. Metacogniton. Extending the understanding. Ideally students would move from applying new the knowledge at the present level of understanding to a deeper synthesis between their current knowledge and the richer emerging knowledge. To do this they have to be encouraged to critically monitor their own learning and take advantage of the classroom session to check their progress. Examples above: (4)(6) (10).

3. Worked-examples

Worked-Examples are learning tools that provide students opportunities to study experts' approaches to problem solving [11]. The experts' solutions are paired with matched practice problems encouraging students to actively explain the examples to themselves. The worked-examples idea was proposed by Sweller whose research showed that traditional practice-based problem solving was less effective for beginning learners than guided study of fully worked out examples [12]. Sweller reasoned from the cognitive load theory perspective that when presented with traditional practice exercises students employ a trial-and-error or pattern-matching approach while students who analyze worked-out examples before being asked to work on their own tend to focus more on structural and conceptual issues.

The worked-examples approach to learning is of particular importance in the initial stages of skills acquisition as defined for example in the Adaptive Control of Thought--Rational model of cognitive architecture which holds that skills acquisition evolves over four overlapping stages. In the first stage learners solve problems by analogy, i.e. they refer to known examples when presented with a problem to solve. In the second stage they develop abstract conceptual schemas that guide their problem solving. After long practice they move to the third stage where the problem-solving process becomes rapid and automatic so that familiar aspects of the process do not consume attention resources. In the fourth stage, after having seen many diverse examples, they can often retrieve solutions directly from long-term memory. The value of the worked-examples approach is very high when the learners are in the first stage, beginning to transition into the second stage, e.g. students in introductory courses.

Worked examples work is paired with self-explanation effects developed by Chi [13] Observing students analyzing worked examples Chi noticed that when reaching an unexplained step, some learners paused and generated their own explanation of the justification for the step. Chi labelled this the self-explanation effect. In our work, we encourage students to self-explain by asking prompting questions.

Over the past twenty years, the worked-examples approach has been studied extensively, mostly in experimental settings, as part of the cognitive load theory research. Factors that moderate the pedagogical effectiveness of worked-examples include a) intra-example features; the intrinsic design of the example; how the solution is presented, b) inter-example features; a careful design of the relationships between multiple examples and c) the design of the prompts that lead the learner through the self-explanation process.

Research has identified three areas of importance when integrating the components: integration of diagrams and text to avoid the split-attention effect, simultaneous use of multiple procedures, such as text and simulations and, when appropriate, calling attention to the solution subgoals [14].

Inter-example features identified by research are the number of examples used per lesson, how the examples are varied and sequenced, how the example themes are used and how examples are intermingled. In general research shows that several examples (at least two) of different complexities, paired with practice problems seems to be the optimal configuration [15].

Self-explanation can be encouraged by structuring the example in such a way that the learner is prompted to self-explain, directly trained in self-explanation (the approach we take in this project) or encouraged to do cooperative group work. Self-explanation is particularly effective when the worked-examples are conceptually oriented and illustrate domain principles.

4. Conclusion

Just-in-Time Teaching Pedagogy, discussed in this article, shows wide variety from discipline to discipline [9] but they share the common feedback loop features described. As such, the JiTT instructional design promotes the three factors identified as the most important for success in college: time on task, student-instructor interaction, and student-student interaction. It is important to appreciate that the choice and implementation of a particular teaching method will impact student and faculty attitudes and motivation as well as learning outcomes.

Teachers using JiTT report a large spectrum of results, ranging from significant affective and cognitive gains to very negative student reactions, disillusionment and even regression in learning gains. We have much anecdotal evidence that in the best of cases, after adopting student-centered teaching approaches such as JiTT, many faculties change their teaching philosophies, sometimes in significant ways. The editors of the JiTT Across the Disciplines book comment that "...the most profound effect comes in changing the way the instructors think about their own teaching, and more important, the learning of their students." [9, p. 135]. Faculty members who once viewed their role as being "conveyors of knowledge" shift to becoming "facilitators of student learning." This developmental shift increases the efficacy of their subsequent teaching, and ultimately increases the levels of "deep learning" experienced by their students.

Successful implementation of the JiTT strategy depends critically on acceptance the students. If the online assignments are seen as an add-on to the course, to be completed perfunctorily in the shortest time possible, and then discussed brie y at the beginning of class, before the "real" lecture, the results will be disappointing. Students will resent the extra work and, in comparison with passive teaching and learning, no gains will be reported.

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